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Title: "Position Detection of an Actuator Using Impedance"
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FIG. 1

| Audio Signal Digital or Analog | → | Signal conversion, analysis and shaping based on speaker/enclosure and preference model.

Present art: Equalization | → Analog Signal → | Power Switch(s) to voice coil/transducer. |

101

102

103

104

105

106

Speaker assembly

100

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FIG. 2

201

Input Signal

202

Input signal optionally adjusted to correct for speaker enclosure distortions:
i.e. frequency response due to resonances, anti-resonaces and phase errors in multi-driver systems

203

Input signal corrected for room distortions:
i.e. frequency response due to resonances, anti-resonances and phase errors

204

Input signal optionally adjusted to user preferences:
i.e. reduction/enhancement of bass, mid tone emphasis for speech/song, hi-frequency emphasis for hearing impaired, etc.

205

Adjustment of signal for multi-driver system:
i.e. phase preserving band pass filter for tweeter, mid range bass, etc.

206

Signal to Output Amplifer

102

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FIG. 3

304
307
312
303
311
308
309
310
302
305
306
301
300

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FIG. 4

$X10 \, L_e \, (mH)$

$Bl(N/A)$

401

403

402

$K(N/mm)$

$x(mm)$

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FIG. 5

Field: Control Systems — 504 — 501 — 509 — 502

Method for Linearizing dynamical evolution equation

Method for decomposing a system into processes

Method for Linearizing a 2nd order equation — 505

Method for linearizing using one state variable — 506

Method for linearizing an actuator or transducer with positional feedback — 507

Method for measuring control loop parameters — 508

Field: Instrumentation

Measurement of actuator or transducer positional state — 510

Positional state derived from internal transducer parameters: Ze, Le, Cp — 511

Positional state derived from external devices: IR diode. — 512

Field: Audio Reproduction — 503

513 — System with three processes

514 — Linearized transduction process with positional feedback

515 — Implementation: methods, software, and apparatus
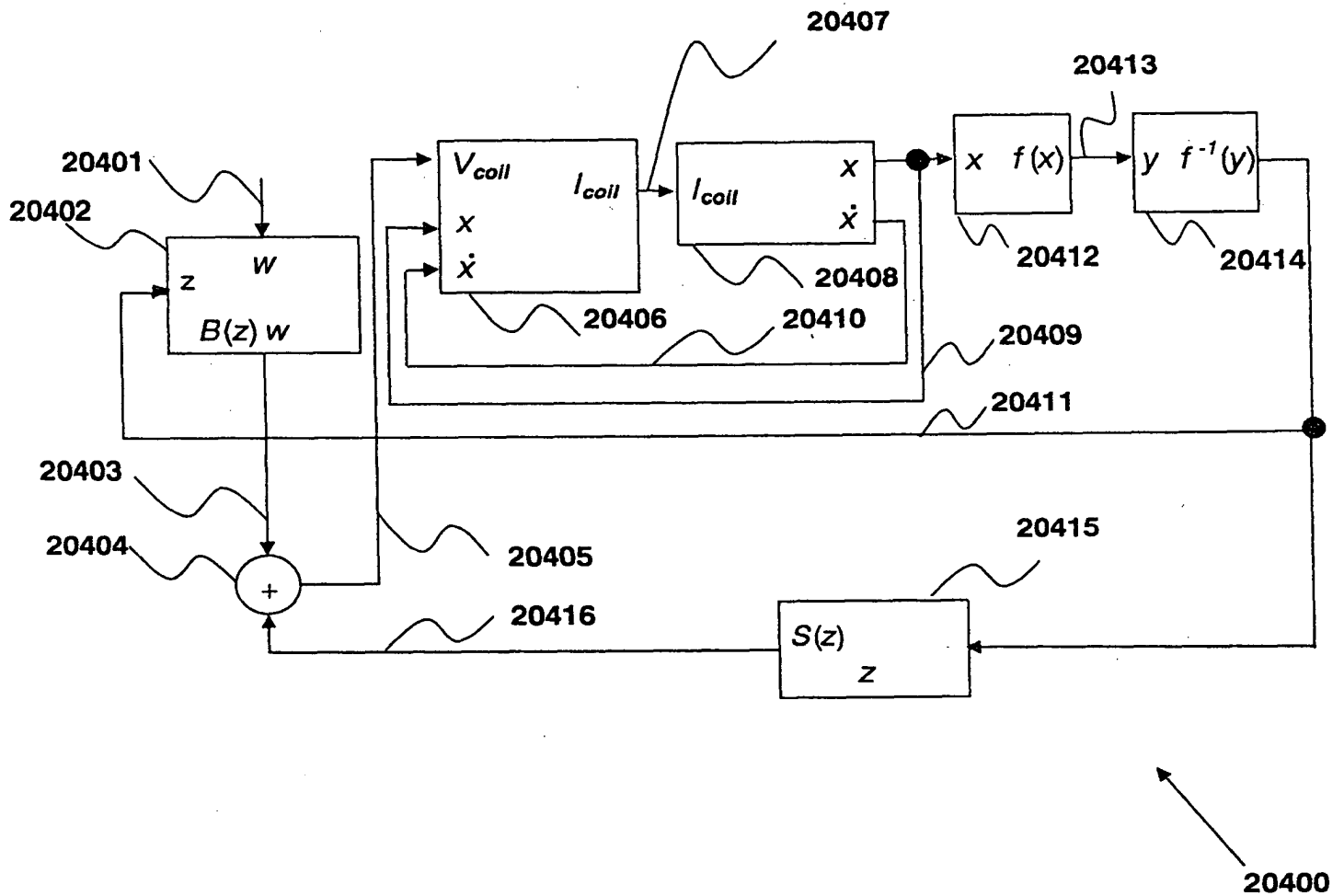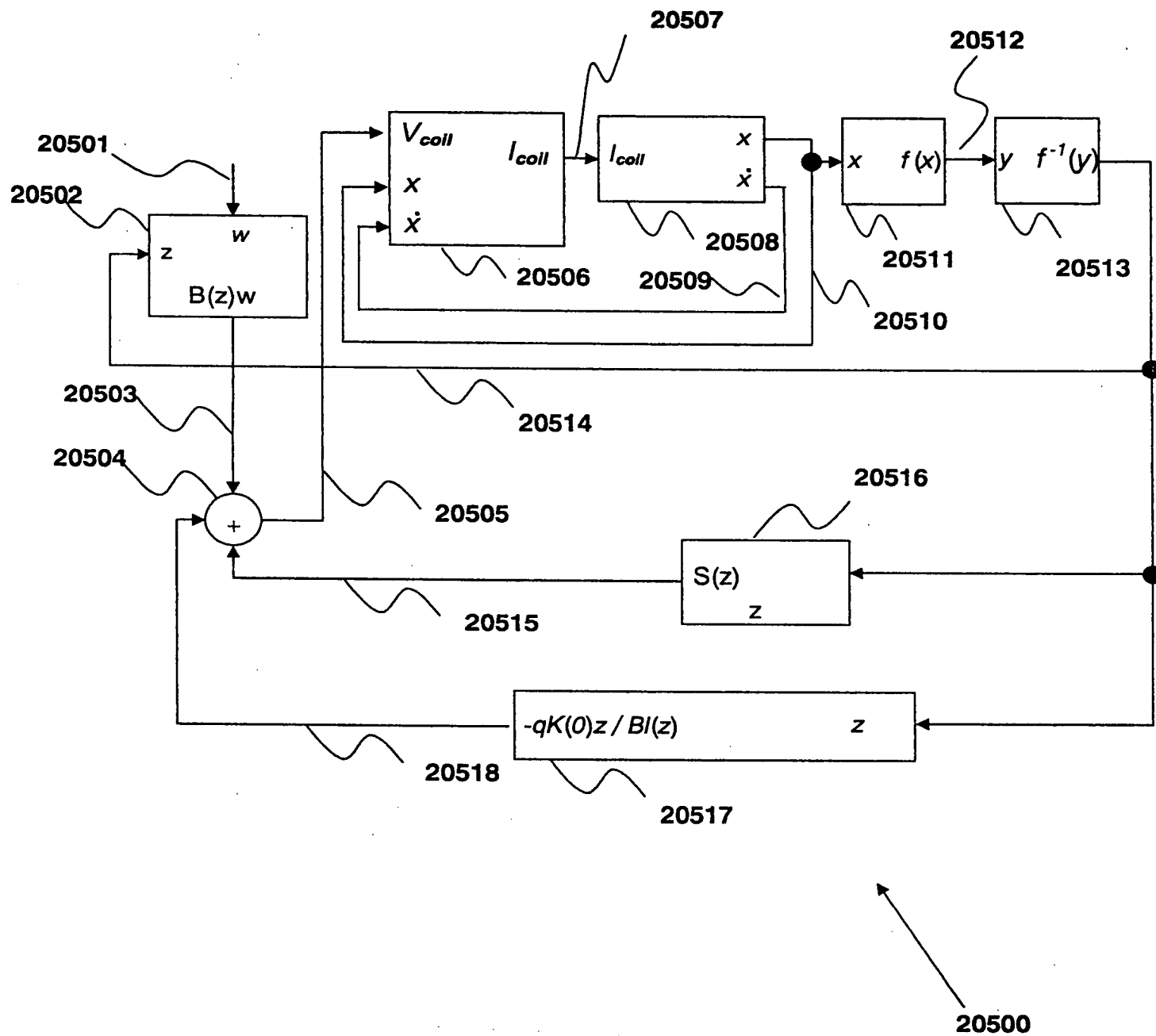
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FIG. 6

SIGNAL CONDITIONING		TRANSDUCTION (Current to Motion)		SOUND CONDITIONING	

Audio Signal →

SIGNAL CONDITIONING

Signal conversion
Amplification
Filtering and equalization
Frequency partitioning

→ **Drive signal** →

TRANSDUCTION
(Current to Motion)

A plurality of
transducers/drivers

→ **Diaphragm Motion** →

SOUND CONDITIONING

Speaker enclosure
and
audio environment

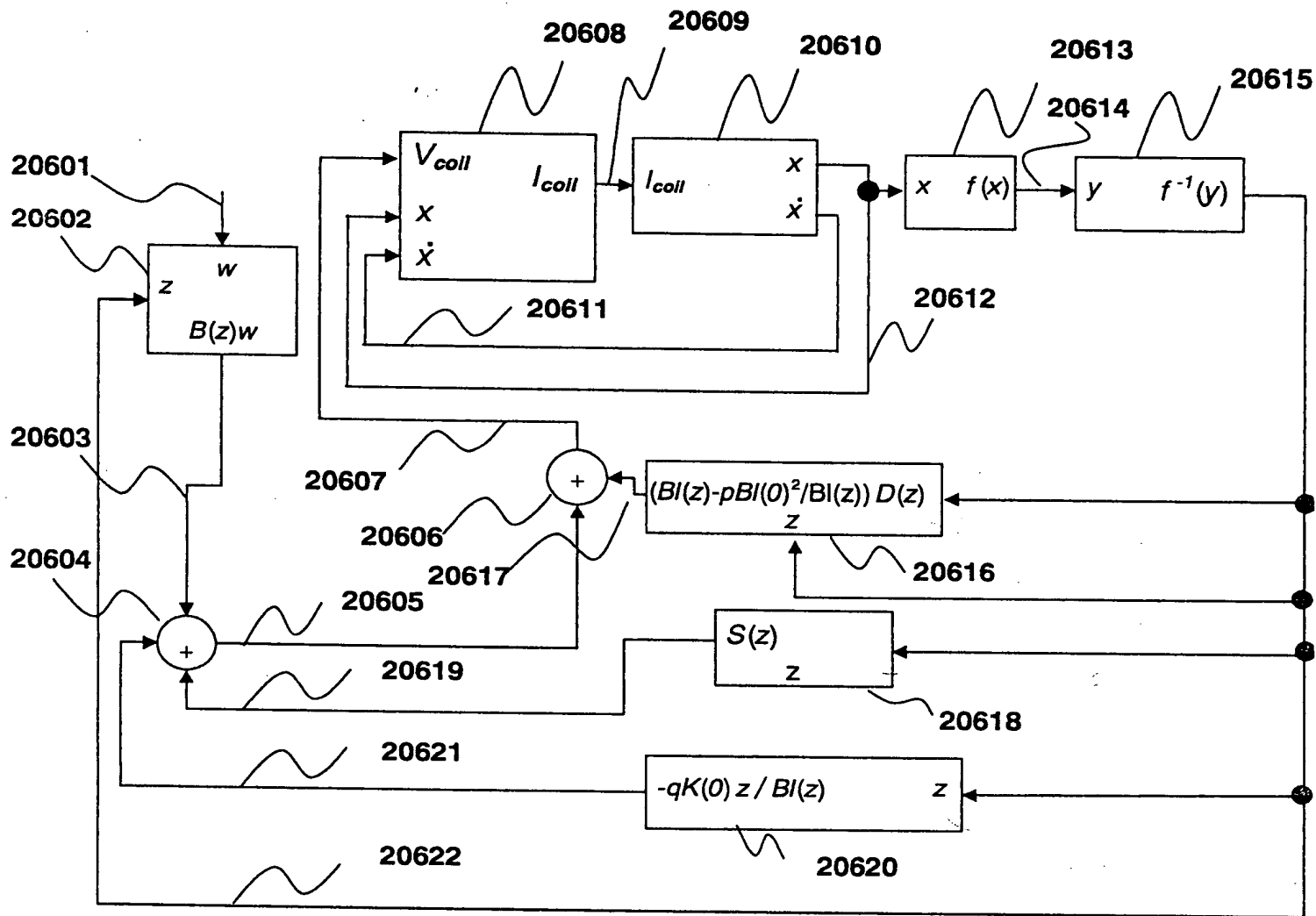→ **Perceived sound** →

1101 1102 1103 1104 1105 1106 1107

1100

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FIG. 7

Provide a model of a portion of the audio reproduction system ⌇ 1301

Utilize a control engineering technique in the time domain based on the model ⌇ 1302

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8/66

FIG. 8

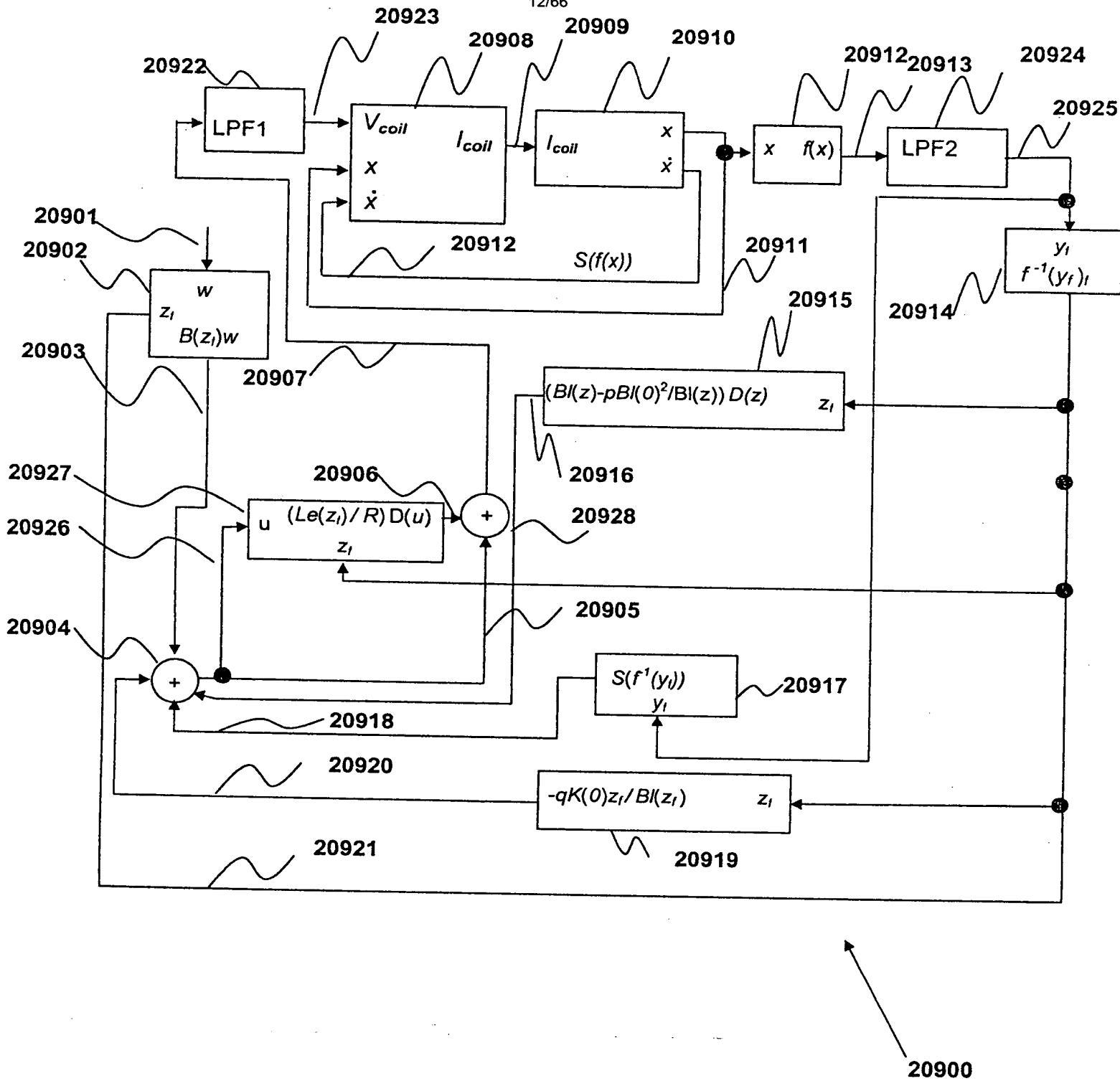Applicant(s): Raymond Browning et al.
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FIG. 9

FIG. 10

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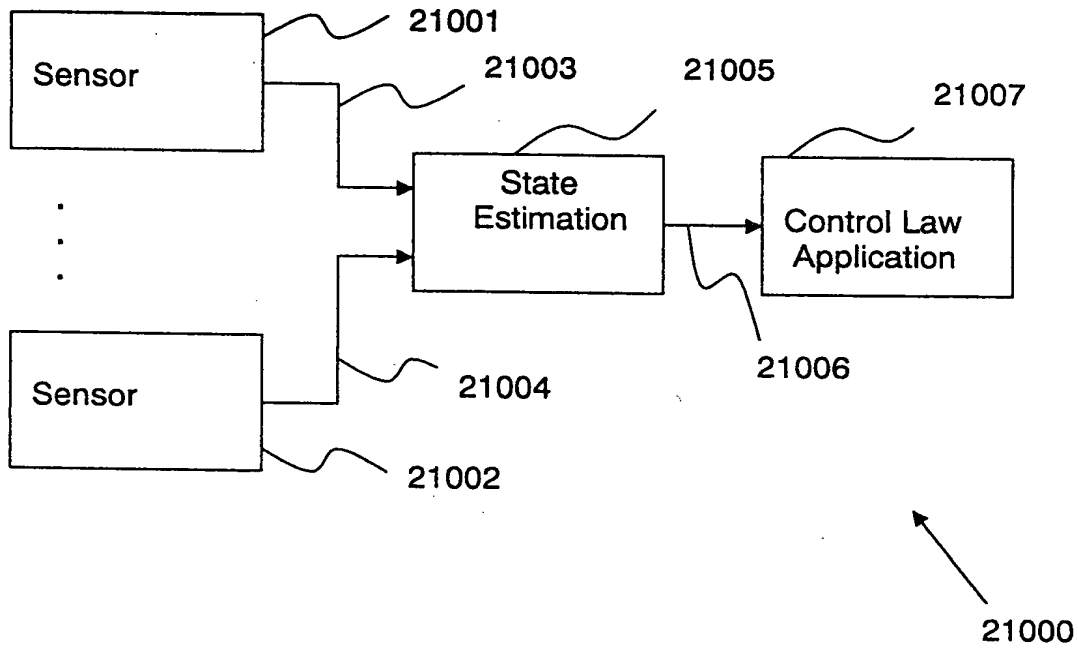Attorney Docket No.: M-15233 US
10/66

FIG. 11

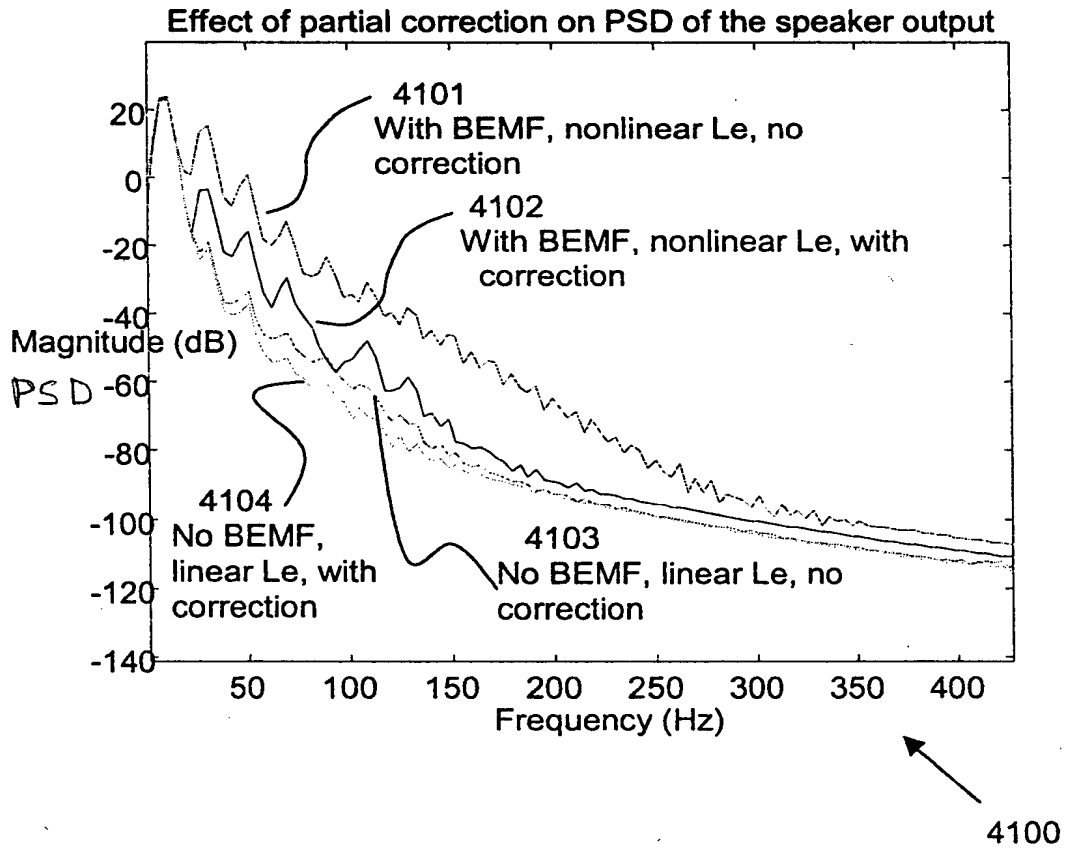Applicant(s): Raymond Browning et al.
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Attorney Docket No.: M-15233 US
11/66

20608   20609   20610   20613   20615
                                   20614

20601

20602

V_{coil} I_{coil} | I_{coil} x | x $f(x)$ | y $f^{-1}(y)$
x | $\dot{x}$
$\dot{x}$

z w

$B(z)w$

20611   20612

20603

20607

20606 $(BI(z)-pBI(0)^2/BI(z))\ D(z)$
                        z
20617

20605   20616

20604

20619 $\dfrac{S(z)}{z}$

                        20618

20621 $-qK(0)\ z\ /\ BI(z)$ z

20622   20620

20600

FIG. 12

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Title: "Position Detection of an Actuator Using Impedance"
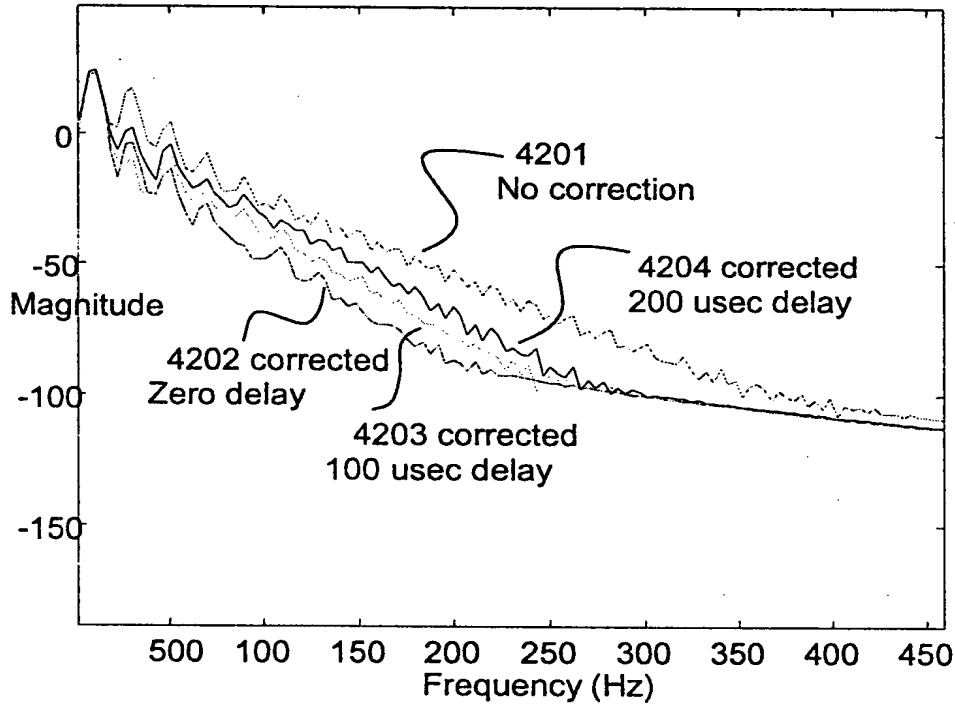Attorney Docket No.: M-15233 US
13/66

FIG. 13

21001

21003   21005   21007

Sensor

State
Estimation

Control Law
Application

21006

Sensor

21004

21002

21000

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14/66

FIG. 14

Effect of partial correction on PSD of the speaker output

4101
With BEMF, nonlinear Le, no correction

4102
With BEMF, nonlinear Le, with correction

4104
No BEMF, linear Le, with correction

4103
No BEMF, linear Le, no correction

4100

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15/66

FIG. 15

PSD of the speaker output (cone velocity) with time-delayed correction

4200

FIG. 16

Effect of Electronically added linear spring

With electronically added linear spring
4301

Displacement

4302
Without electronically added linear spring

Time

4300

FIG. 17

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Electronically implemented linear spring in the absence of Bl(x) effect

FIG. 18

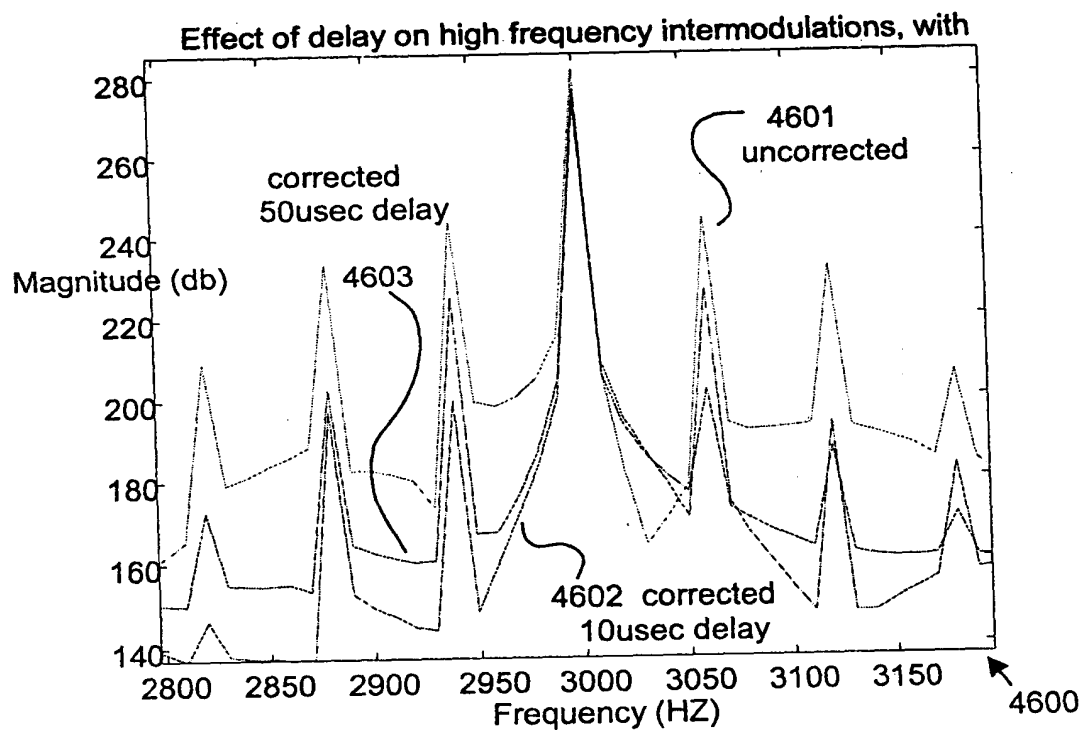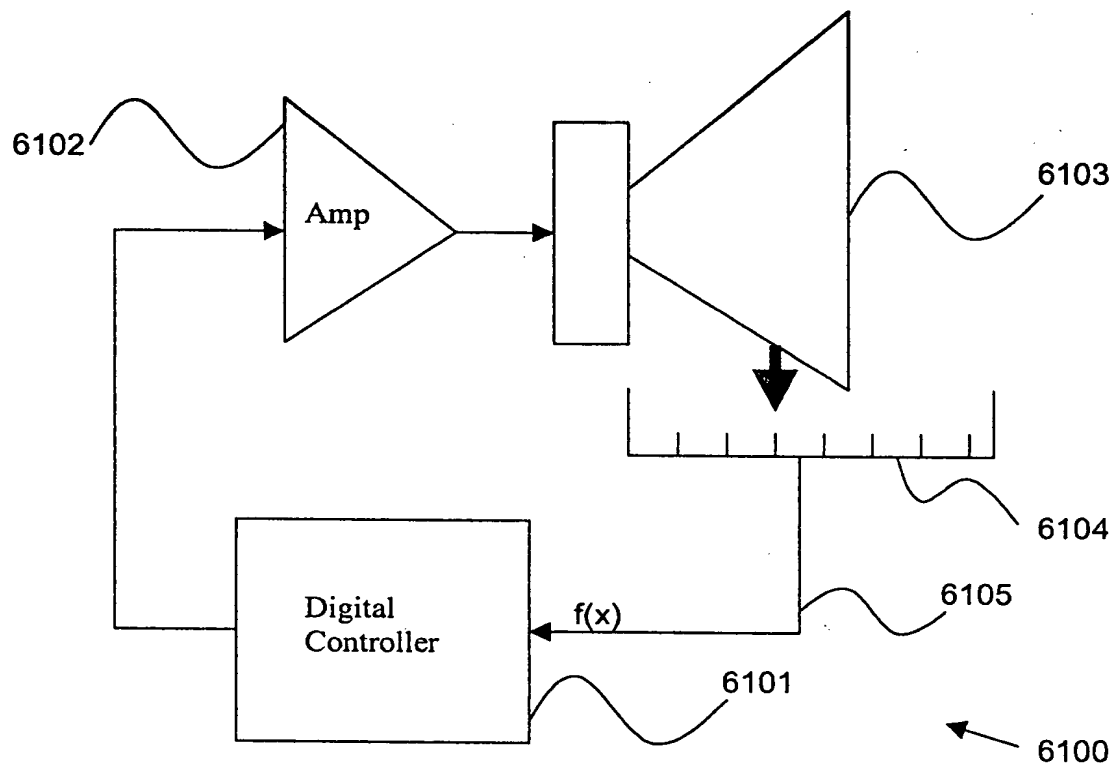Applicant(s): Raymond Browning et al.
Title: "Position Detection of an Actuator Using Impedance"
Attorney Docket No.: M-15233 US
18/66

BEMF induced phase between the speaker current and voltage

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19/66

FIG. 19

Effect of delay on high frequency intermodulations, with

FIG. 20

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Title: "Position Detection of an Actuator Using Impedance"
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FIG. 21

Begin

6201   Output V(n)   Increment n

6202   Wait for settling

6203   Measure f(x)

6204   Last step ?

6205   End

FIG. 22

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FIG. 23

Applicant(s): Raymond Browning et al.
Title: "Position Detection of an Actuator Using Impedance"
Attorney Docket No.: M-15233 US
23/66

6301

Audio
input

Digital
Controller

6302

6305

6306

Amp

6304

f(x)

6303

6300

FIG. 24

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Title: "Position Detection of an Actuator Using Impedance"
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Applicant(s): Raymond Browning et al.
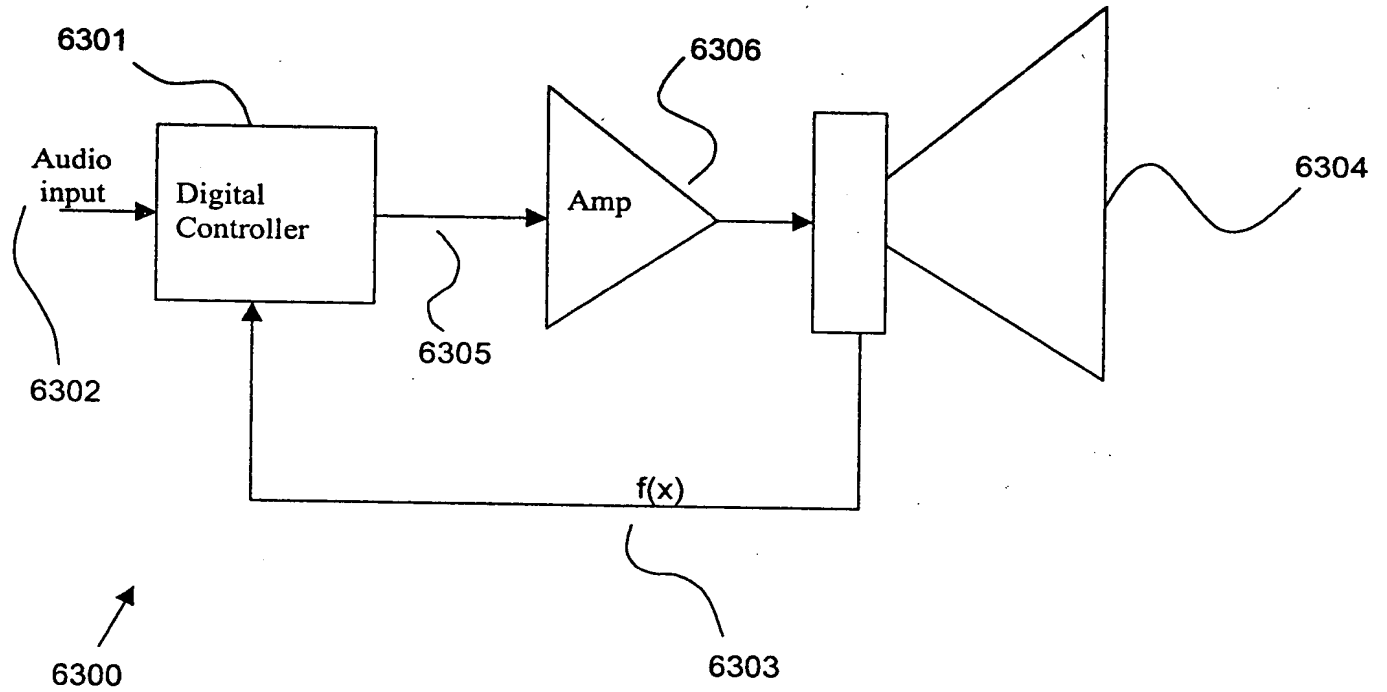Title: "Position Detection of an Actuator Using Impedance"
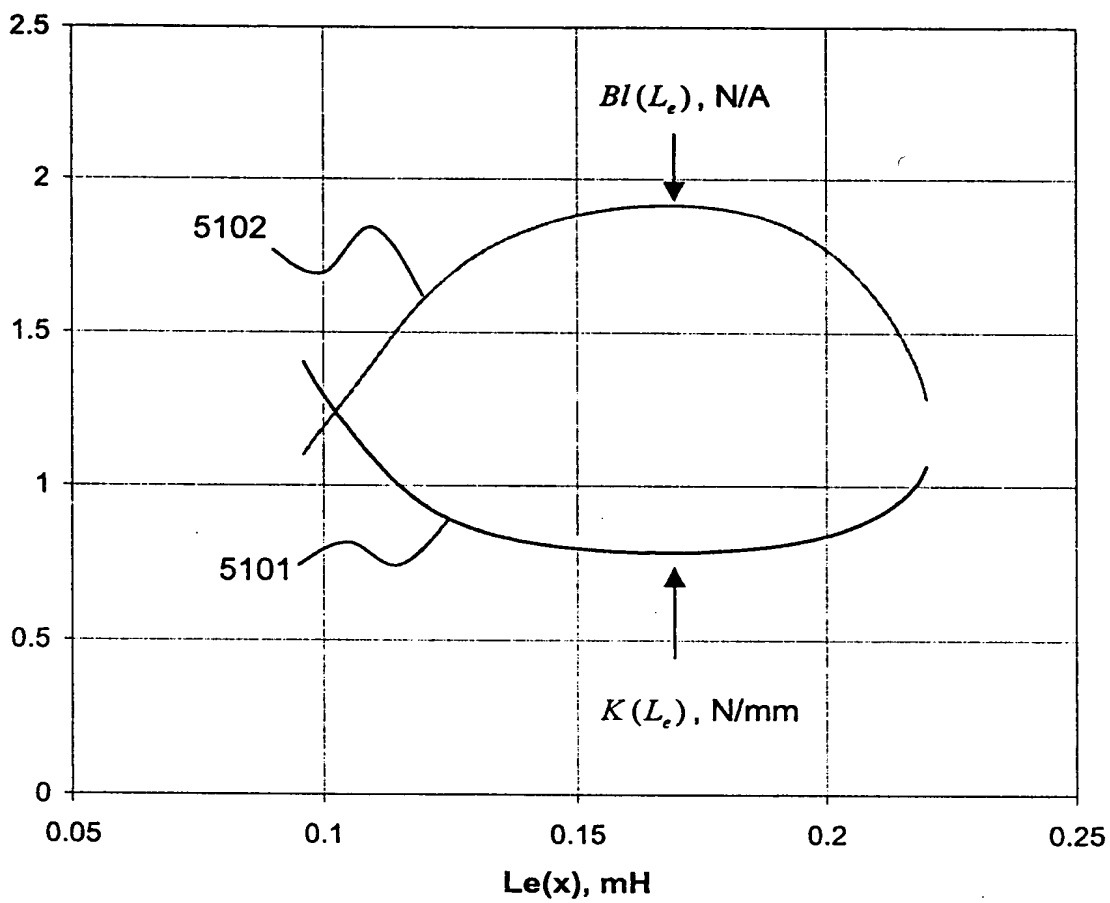Attorney Docket No.: M-15233 US
25/66

FIG. 25

FIG. 26

L_e vs. Coil Displacement at 43 kHz

FIG. 27

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Magnitude plot (dB) 7200

High Le 7201

Low Le 7202

Frequency (rad/sec)

Applicant(s): Raymond Browning et al.
Title: "Position Detection of an Actuator Using Impedance"
Attorney Docket No.: M-15233 US
28/66

FIG. 28

High Le
7204

Low Le
7205

Phase plot (deg)
7203

Frequency (rad/sec)

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Attorney Docket No.: M-15233 US
29/66

FIG. 29

Magnitude plot (dB)
7300

High Re
7301

Low Re
7302

Frequency (rad/sec)

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FIG. 30

Phase plot (deg)
7303

Low Re
7305

High Re
7304

Frequency (rad/sec)

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FIG. 31

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FIG. 32

FIG. 33

C Test with Cant

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FIG. 34

Face Plate
13106

Surround
13105

13207

Diaphragm
13102

Neodymium
Magnet
13103

Cell Phone Speaker
(Receiver)
13100

Magnetic
Base Plate
13104

Coil mounted
on diaphragm
13101

Acoustic
Vents
13107

D1

FIG. 35

FIG. 36

FIG. 37

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Reflecting region
14204

14206

14205

14104

IR-LED
14201

PIN Diode
14202

14203

14200

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FIG. 38

FIG. 39

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15101 10101 15102 15109 20:1

ATTENUATOR

15110

Marchand
Amplifier
PM224

15108

Innovative M67

15103   A4D4

15112

IR Detector
(optics and circuit)

Xir = f(x)

15111

15113

15104

Lynx L22 Card

15105

15107

15106

Cool Edit
(generates .wav file)

CD Player

PC - eMachines T1742

15100

FIG. 40

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| Measure Transducer LS Parameters | 111001 |

| Invoke Software Control Program | 111002 |

| Operate Software Control Program in Calibrate Mode to calibrate f(x) with x And S with f(x) | 111003 |

| Find 'Best Fit' Coefficients with Lowest Order Polynomials S, x, Bl and Le | 111004 |

| Insert S, X, Bl and Le Coefficients into Program | 111005 |

| Invoke Software Control Program | 111006 |

| Operate Software Control Program in Normal Mode | 111007 |

| Use Keyboard to change 'tuning' parameters for S(x),S(0),B,BEMF(x), BEMF(0), Le(x), Le(0) | 111008 |

LS = Large Signal

FIG. 41

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41/66

From 111002 or
From 111006

Initialization — 111101

User Mode Select — 111102

111103

C   NM   Exit — 111105

ISR

111104

111106

Stop Program — 111107

NM: Normal Mode
C: Calibration mode

FIG. 42

From user mode select
111102

111103

Get user inputs;
Initialize and start output to DAC;
Enable ADC and DAC triggers
Initialize array with S drive values;
Initialize, setup & enable Interrupt Service Routine.

11501

11502

Setup Sampling Clock (SC) and Enable SC
(Starts operations of HW and ISR)

11504

Continue with mainline loop

11503

11505

Execute HW and ISR operations

Operate Mainline S Calibration
Loop

FIG. 43

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From Setup Sampling Clock and Enable SC 11502

Sampling Clock
HW Operation — 11601

ADC Convert
HW Operation — 11602

Limit dacvalue from last sample; send limited dacvalue to DAC via serial port. — 11604

DAC Convert
HW Operation — 11605

11603

Collect_data? — 11606

No   Yes

Read sensor data f(x) & x; store data into sensor sample arrays; tally sample count. — 11607

Read dacvalue from S array — 11608

Return from ISR — 11609

ISR

Note: All operations are in SW, unless indicated otherwise

To Operate Mainline S Calibration Loop 11505

11504

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FIG. 44

From Continue with mainline loop 11503

11505

11701 — S values left?

Yes   No

11702 — Wait 100 milliseconds

11703 — Set Collect_data

11704 — Wait 1 millisecond

11705 — Clear Collect_data

11706 — Average f(x) & x using sample count from SC ISR

11707 — Store S, f(x), and x

11708 — Disable sampling clock & interrupts

To user mode select 111102

All operations are in SW

FIG. 45

From user mode select
111102

111104

11201

Get user inputs.
Initialize and start output to DAC;
Enable ADC and DAC triggers
Initialize & setup Interrupt Service Routine (ISR).

11202

Enable ISR.
Setup and Enable Sampling Clock (SC)

11203

Make
adjustment
or stop

11204

Execute normal mode
HW & ISR operations

Wait Loop & Command Parser

To user mode select
111102 or ISR 111106

FIG. 46

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From Wait Loop
and Command
Parser 11204

From Enable ISR, Setup
and Enable Sampling
Clock (SC) 11202

11203

Sampling Clock

HW Operation

11301

ADC Convert

HW.Operation

11302

ISR

SW Operation

11303

To Wait Loop and Command
Parser 11204

FIG. 47

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11303

From Sampling Clock 11301 and
Wait Loop & Command Parser 11204

11401

Limit dacvalue from last
sample; send limited dacvalue
to DAC via serial port

11402

DAC Convert
HW Operation

Read sensor data f(x) from ADC   11403

Filter sensor data
(to reduce noise)   11404

Read audio sample from ADC   11405

Compute S, Bl, B and Le from f(x)   11406

Compute df(x)/dt
from f(x)   11407

11408

Compute corrected Vcoil

dacvalue = Vcoil   11409

Return from ISR   11410

All operations are in
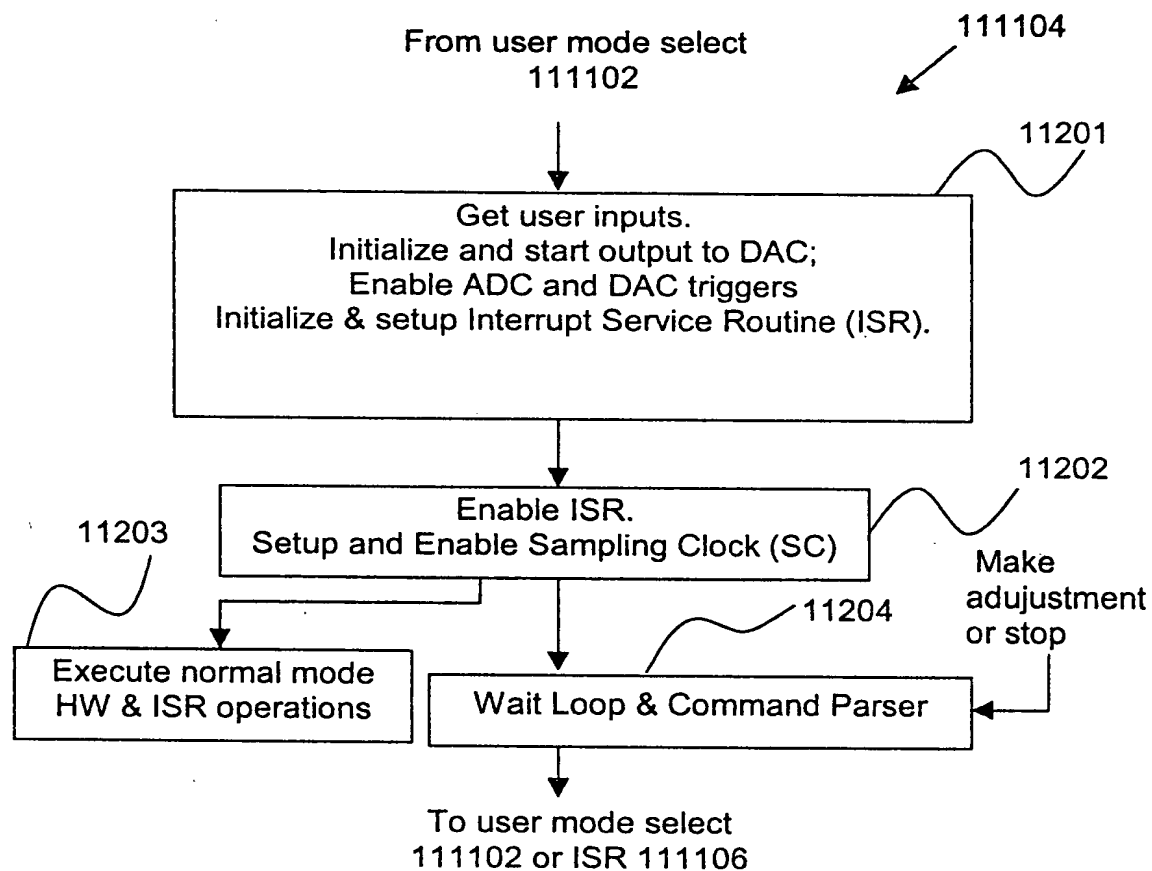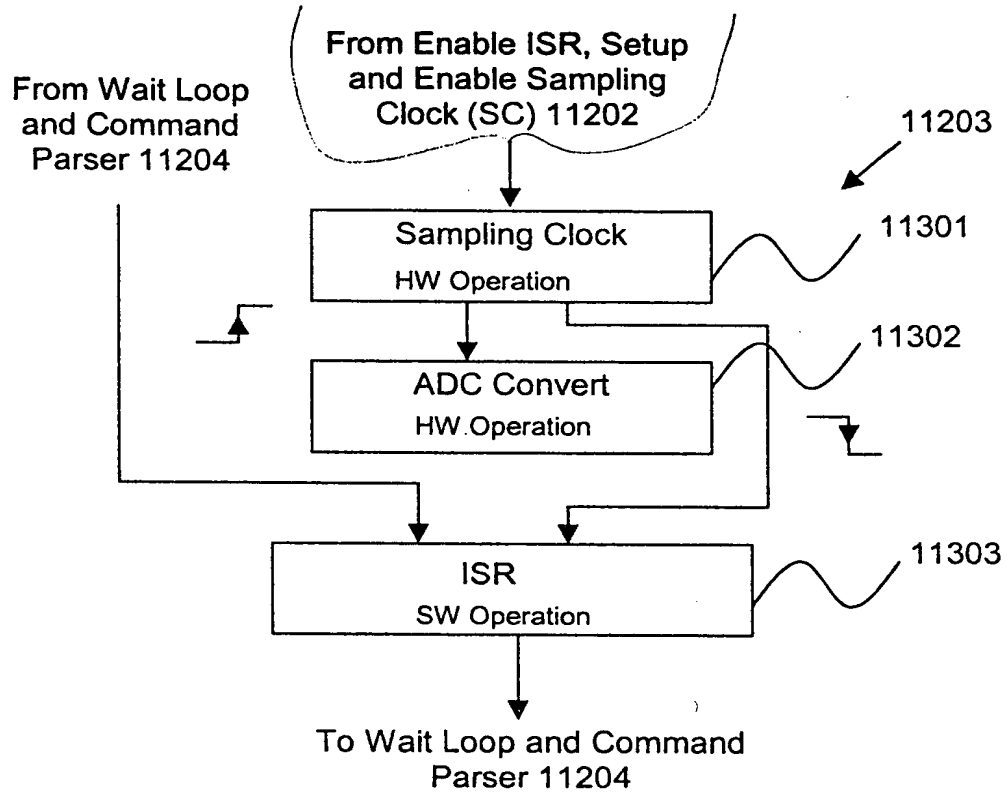SW, unless indicated
otherwise

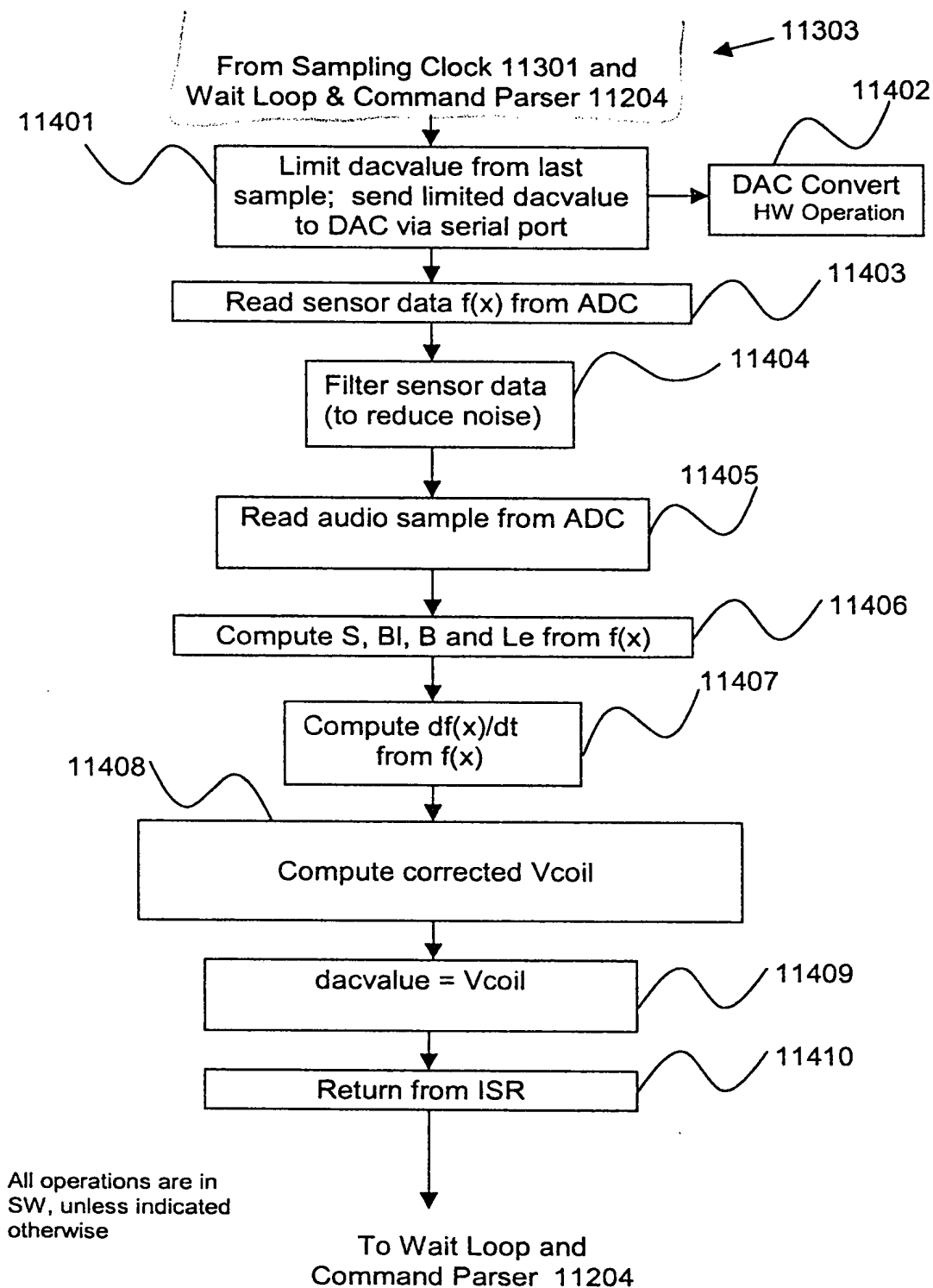To Wait Loop and
Command Parser 11204

FIG. 48

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From Enable ISR Setup and Enable Sampling Clock (SC) 11202

Stop? 11801

Yes → **Disabl Interrupt and put HW into Known State** 11803 → To User Mode Select 111102

No

Command? 11802 — No

Yes

11804 c — **Corrected Audio Mode** 11805

b — **Adjust Linear BEMF** 11806

Increase Volume

11807 u — **Uncorrected Audio Mode**

i — **Adjust dL/dx Correction**

+ **Decrease Volume** 11808 / 11809

11810 o — **Adjust Offset**

11811 j — **Adjust dL/dx Offset**

- **Mute On** 11812

11813 k — **Adjust Linear Spring**

f — **Turn IR Filter On**

m — **Mute Off** 11814 / 11815

11816 v — **Adjust Nonlinear BEMF**

n — **Turn IR Filter Off**

d — **Stop** 11817

s 11818

11204

FIG. 49

From Operate Software Control
Program in Calibrate Mode 111003

111004   111201

Offline Preliminary curve fitting

111203

Select mid sections of S drive, laser data x, & IR sensor data f(x)

111204

Using Matlab polyfit, fit polynomials: S and x versus f(x)

111205

Do composition of functions using Mathcad to
obtain polynomials for Bl, and Le versus f(x)

111206

Reduce order of polynomials of Bl, and Le while maintaining
error over range of f(x)

111202

Polynomial order reduction for
specified error levels

111207

Specify desired RMS and max errors for S, x, Bl & Le

111208

Run 'Best Fit' polynomial order reduction on S, x, Bl, & Le;
print results for specified errors

All Errors Cases Done?   No

111209

Yes

Select order (& coefficients) of polynomials for S, x, Bl and Le   111210

To Insert S, x, Bl, Le Coeffs.
into Program 111004

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FIG. 50

From Specify desired RMS and max errors for S, x, BI & Le 111207

111208

Specify range of f(x), mid section of f(x) and weights for mid section of f(x)

111301

Specify input and output file names for S, x, BI & Le

111302

111303

For each of S, x, BI & Le reduce order of polynomial sequentially

111304

Supply Coefficients of Next Curve

111305

Reduce the order of given polynomial (curve) for specified desired RMS and max errors using 'Best Fit' approach; output result

4 Curves Done? — No

111306

Yes

Print pass or fail result and coeffs. of each of S, x, BI, and Le

111307

To All Errors Cases Done? 111209

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Title: "Position Detection of an Actuator Using Impedance"
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FIG. 51

From Supply Coefficients of Next Curve
111304

111305

Let Y represent the given curve's coefficients;
using given coefficients, calculate Y_{orig} values for a range of f(x)
values and set the specified weights for each point

111401

Reduce the order of coeffs by 1

111402

111403

Compute new coefficients using weighted least squares
algorithm to 'Best-Fit' calculated Y_{orig} values

111404

Compute Y values with new coefficients for each range value of
f(x) above; compute RMS and max errors between Y_orig and Y
values

Errors > specified ? — No

111405

Yes

Order reduced ? No

111406

111407

Yes

Declare Fail: Ouput original coeffs.

111408

Declare Pass: Output reduced order coeffs.

To 4 Curves Done?
111306

FIG. 52

12100

12102

Ze(x)

12101

12104

Zref

12103

FIG. 53

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Probe tone

12101

12200

12202

12503

12601

12207

Probe tone → (+) → | Potential divider | → | High pass filter | → | Bridge detector | → | Low pass filter | →

12403

12201

12203

12204

12205

12206

Audio drive
signal

FIG. 54

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54/66

12302

12301

12303

ADI-21992
EZ-KIT

12201

12305

Ze(x) Detection
System

12200

12101

12207

12304

Sine wave
generator

FIG. 55

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12201

124R1
1.0 Ω

124R2
1.0 Ω

124L1
24 µH

124C1
2.0 µF

124C2
4.7 µF

124C3
4.7 µF

124L2
100µH

124C4
1.0 µF

12403

12101

12402

12401

12202

FIG. 56

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12403

125R1
1 kΩ

12501

125R3
12 kΩ

12504

125C1
1 nF

125C2
1 nF

LM741

12502

125L1
60 mH

125R1
12 kΩ

125R2
1 kΩ

12503

12203

12204

FIG. 57

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FIG. 58

12206

12601

127C1
10 nF

127R4
5.6 kΩ

127R5, 5.6 kΩ

127R1
15 kΩ

127R3
15 kΩ

127OA1
LM741

127R2
10 kΩ

127C2
10 nF

127R7, 330 Ω

127R8, 330 Ω

127C4
10 nF

127R9, 6.8 kΩ

127C1
100nF

+5v

127VR1
50 kΩ

127OA2
LM741
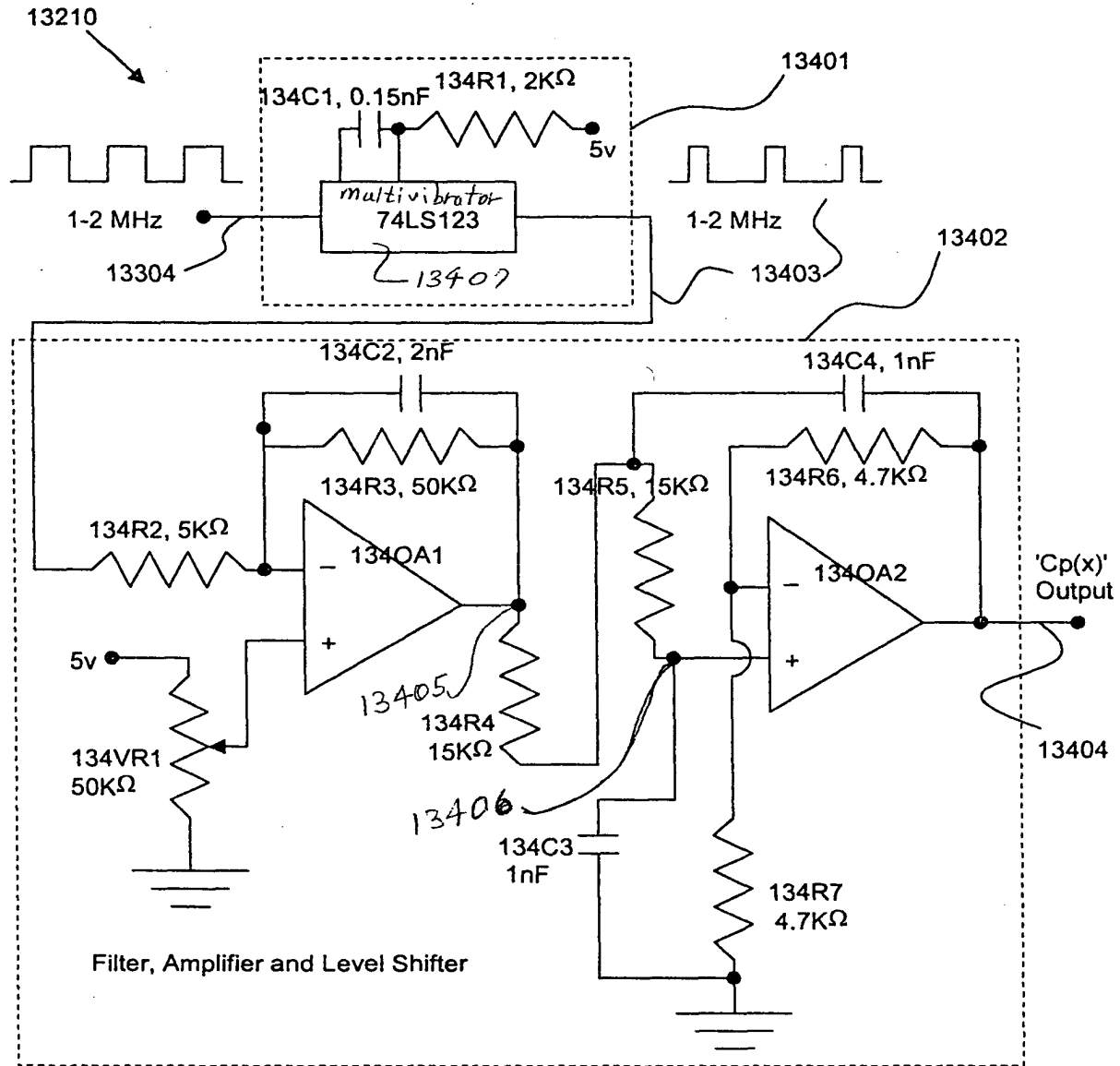
12207

FIG. 59
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Attorney Docket No.: M-15233 US
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12305

128R1, 1 kΩ

128R2, 1 kΩ

12303

128OA1
LM741

+5v
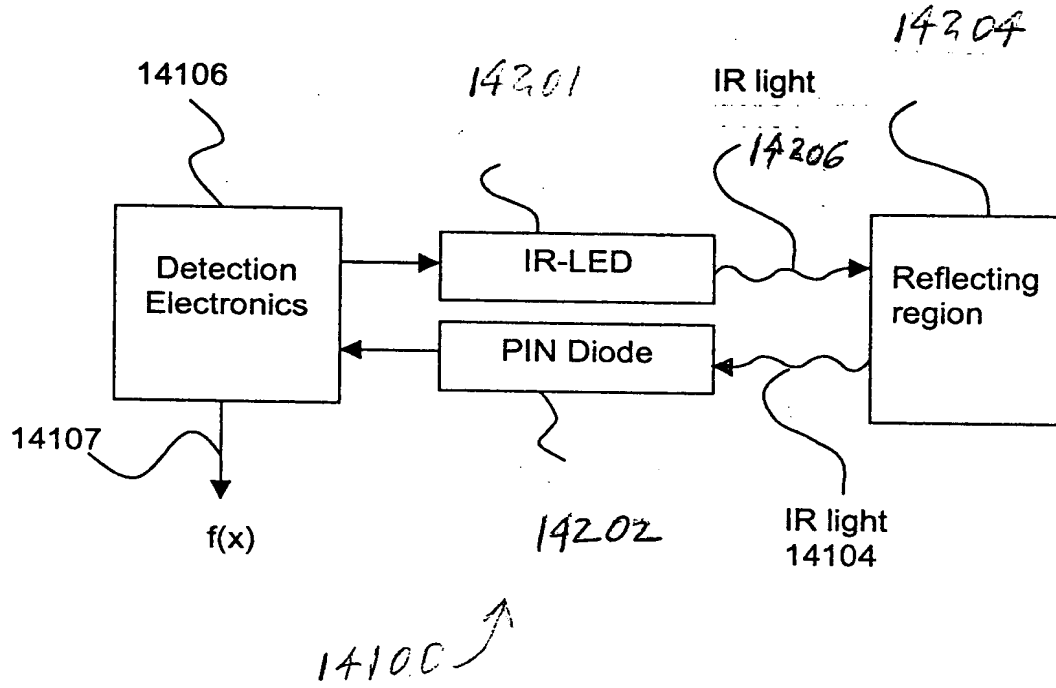
128VR1
50 kΩ

128R4, 10 kΩ

128R3, 1 kΩ

128OA2
LM575

12201

FIG. 60

FIG. 61

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FIG. 62

Filter, Amplifier and Level Shifter

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FIG. 63

14106

14301

14204

IR light

14206

Detection Electronics

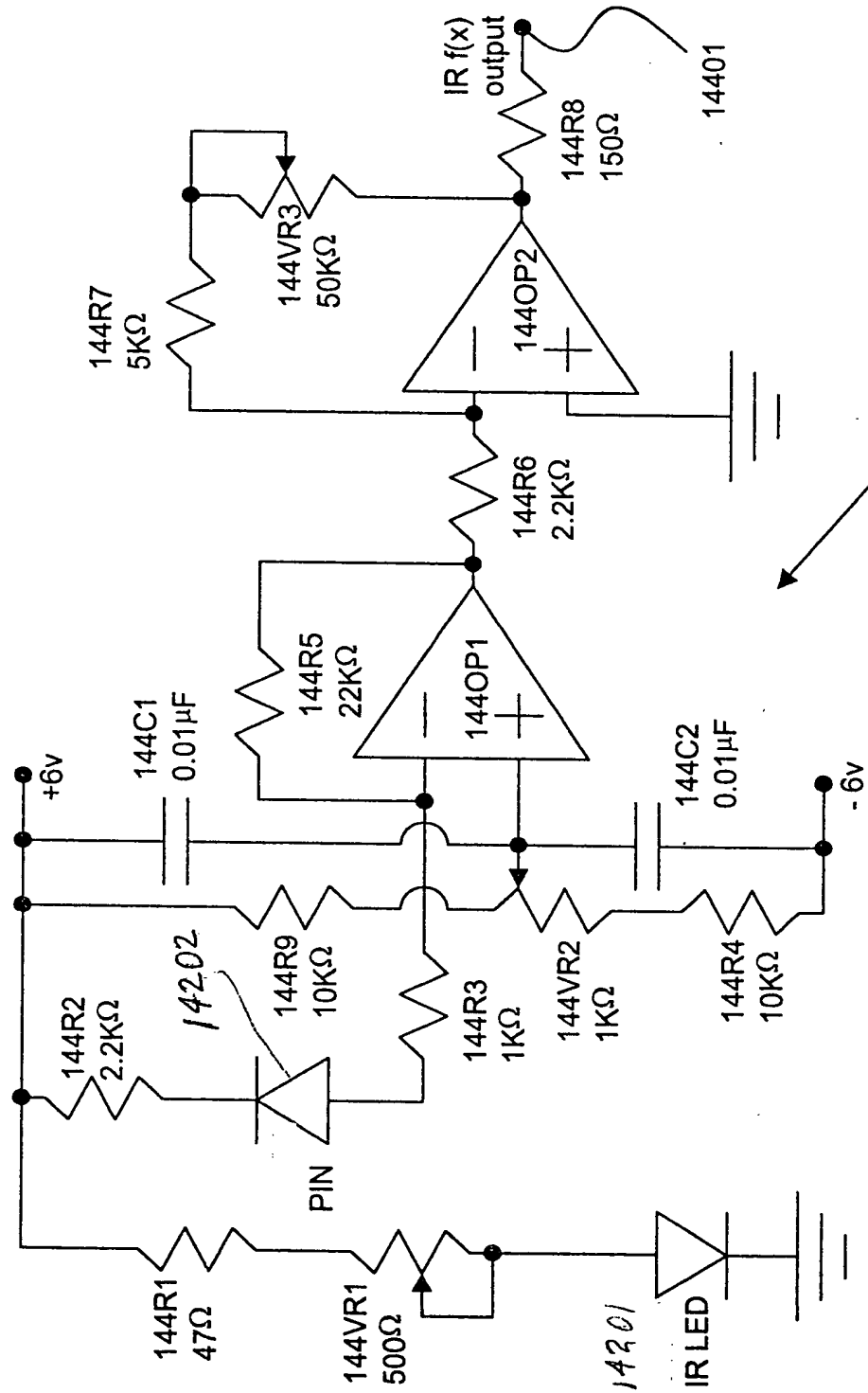IR-LED

Reflecting region

PIN Diode

14107

f(x)

14202

IR light
14104

14100

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FIG. 64

IR f(x) output

144R8
150Ω

14401

144VR3
50KΩ

144R7
5KΩ

144OP2

14106

144R6
2.2KΩ

144R5
22KΩ

144OP1

+6v

144C1
0.01μF

-6v

144C2
0.01μF

144R2
2.2KΩ

14202

144R9
10KΩ

144R3
1KΩ

144VR2
1KΩ

144R4
10KΩ

PIN

144R1
47Ω

144VR1
500Ω

14201

IR LED

FIG. 65

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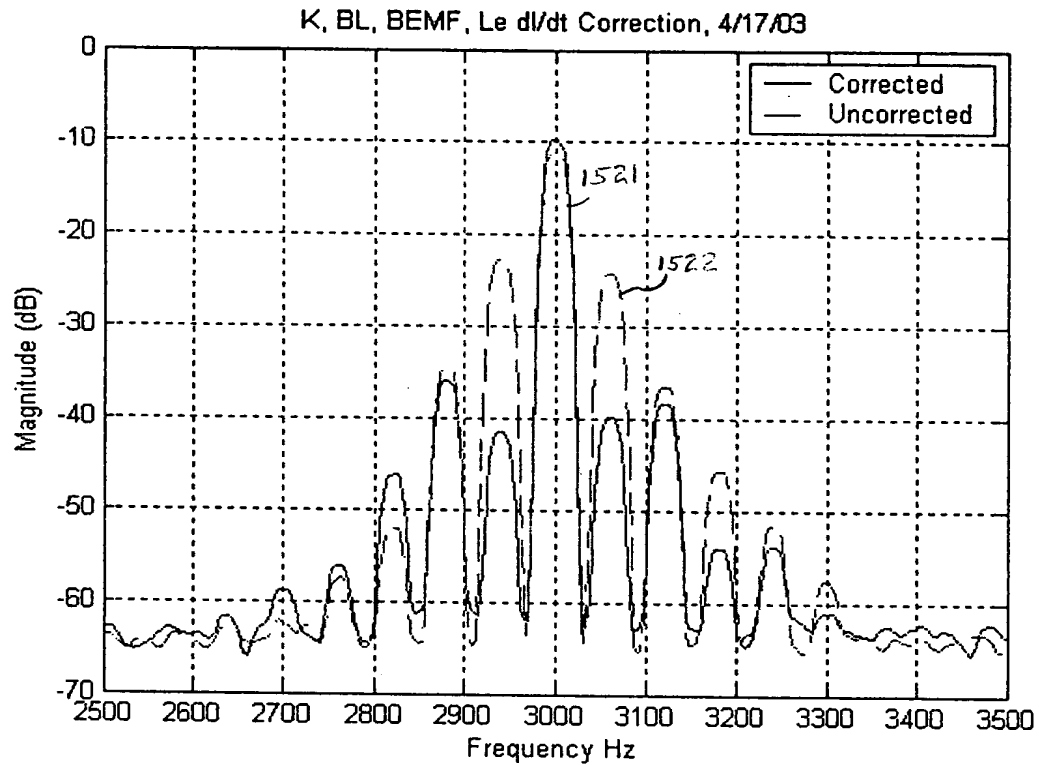Attorney Docket No.: M-15233 US
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K, BL, BEMF, Le dI/dt Correction, 4/17/03

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Title: "Position Detection of an Actuator Using Impedance"
Attorney Docket No.: M-15233 US
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FIG. 66

K, BL, BEMF, Le dl/dt Correction, 4/17/03